Effect of Vacuum-Steam-Vacuum Treatment on Microbial Quality of Whole and Fresh-Cut Cantaloupe†

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ABSTRACT

Minimally processed fruits and vegetables have a limited shelf life because of deterioration caused by spoilage microflora and physiological processes. Cutting may increase microbial spoilage of fruits through transfer of microflora on the outer surfaces to the interior tissue. The objectives of this study were to use the vacuum-steam-vacuum (VSV) process to reduce indigenous spoilage microflora on the surface of cantaloupes and to investigate the effects of such treatments on transfer of spoilage microflora from the cantaloupe surface to the fresh-cut melon during rind removal and cutting. Whole cantaloupes were treated in the VSV processor, and fresh-cut pieces prepared from treated and control samples were stored at 5 and 10°C for up to 9 days. Presence and growth of mesophilic bacteria, yeasts and molds, and *Pseudomonas* spp. were determined in fresh-cut samples during storage. Texture and color (CIE L*, a*, and b*) also were measured during storage. VSV treatment resulted in a 1.0-log reduction of aerobic mesophilic bacteria, a 2.0-log reduction of yeasts and molds, and a 1.5-log reduction of *Pseudomonas* spp. on cantaloupe surfaces. VSV treatment significantly reduced transfer of yeasts and molds and *Pseudomonas* spp. from whole cantaloupe surface to fresh-cut pieces during preparation ($P < 0.05$). Texture and color of the fresh-cut pieces prepared from the VSV-treated whole melons were similar to those of the controls. The results of this study indicate that the use of the VSV process to reduce the surface populations of yeasts and molds and *Pseudomonas* spp. on whole cantaloupes will reduce subsequent transfer of these microbes to fresh-cut pieces and enhance the microbial quality of the fresh-cut product.

The level of sanitation during processing and shipping and at retail outlets and the initial microbiological load are of primary importance to the quality, shelf stability, and safety of fresh produce *(4, 6)*. Melons are frequently in contact with soil, insects, animals, and humans during growth in the field and during harvesting. Thus, their surfaces are exposed to natural contaminants, and at the packinghouse melon surface populations are 10^4 to 10^6 microorganisms per gram *(4, 6)*. Contamination with human pathogens most likely comes directly or indirectly from fecal matter, either pre- or postharvest, and may involve use of contaminated irrigation water or uncomposted manure *(23)*. Contributing factors include poor hygiene and unsanitary practices of field, packing, and processing workers, inadequate cleaning of processing equipment, the use of decayed or damaged melons, and failure to wash melons properly before fresh-cut processing *(4, 6, 23, 24)*.

Chlorinated wash water (up to 200 ppm) is routinely applied to reduce microbial contamination in produce processing lines *(34)*. However, the use of chlorine is of concern because of the potential formation of harmful by-products *(26)* and can only achieve approximately 1- to 2-log reductions in native microflora *(29)*. Thus, there is much interest in developing a safer and more effective alternative treatment. We have investigated the use of hot water treatment for decontamination of whole cantaloupes designated for fresh-cut processing, and the results suggest that this treatment would have major advantages over the use of sanitizers by greatly reducing or eliminating vegetative cells of spoilage organisms and pathogenic bacteria on melon surfaces *(31)*. Recently, Annous et al. *(2)* reported similar findings and concluded that surface pasteurization of whole cantaloupes could achieve a 5-log reduction of bacterial populations on melon surfaces.

Agricultural Research Service engineers developed and patented the vacuum-steam-vacuum (VSV) process for reducing bacteria on the surfaces of solid foods, especially raw food, without causing thermal damage to the food *(12, 13, 19–22)*. VSV surface intervention employs a short exposure to vacuum to remove any insulating fluids, followed by a quick burst of condensing steam that rapidly transfers energy directly to the contaminated sample. A second exposure to vacuum evaporatively cools the product surface, preventing thermal damage. Although the surface debris is removed with the initial application of vacuum, the condensing steam itself continuously deposits an insulating water (condensate) layer during processing. Cycling between vacuum and steam effectively removes this redeposited water layer as soon as it forms and improves surface treatment. Microstructure of the netting gives the cantaloupe rind inherent surface roughness likely to favor bacterial attachment and complicates detachment by chemical treatments

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(29). Because the VSV process is designed to reduce bacteria on the surface of raw food, we hypothesized that the vacuum process allows penetration of the steam into crevices and pits to reduce spoilage microflora on cantaloupe surfaces with little or no thermal damage to the flesh. In this study, our objectives were to investigate the use of the VSV process to reduce indigenous spoilage microflora on the surfaces of cantaloupes designated for fresh-cut processing. We also investigated the effects of such treatments on transfer of spoilage microflora from the cantaloupe surface to the fresh-cut pieces during rind removal and cutting. The effects of such treatment on the color and texture of the fresh-cut cantaloupe were monitored during storage at 5 or 10°C for up to 9 days.

MATERIALS AND METHODS

Unwaxed cantaloupes (*Cucumis melo* L. var. *cantalupenis* Naud., 1,802 ± 62 g, western shippers) were purchased from a local wholesale distribution center. Melons were stored at 5°C for ~18 h before use and then placed on the laboratory bench for 20 h to allow them to come to room temperature (~20°C). The melons were then subjected to the VSV treatment.

VSV treatment. The surface intervention processor was designed to process whole raw foods such as chicken carcasses. Samples are placed individually into a treatment chamber, the chamber is evacuated, saturated steam is injected into the chamber, a vacuum is created in the chamber to evaporatively cool the sample, and the sample is ejected into a clean environment. The treatment chamber has a spherical valve 254 mm in diameter *(12)*. Each whole cantaloupe was manually inserted into the treatment chamber of the VSV processor. The treatment chamber has a computer controlled ball valve with a servo that was rotated at 90° to seal the treatment chamber from the outside atmosphere. Platter valves on the sides of the treatment chamber rotated to expose the melon to vacuum, then steam, and then vacuum again. With multiple cycles, the sequence of vacuum and steam was repeated a specified number of times. After treatment, the ball valve was rotated 90° to expose the cantaloupe to the room atmosphere, and the cantaloupe was manually removed with sterile gloves. Whole cantaloupes were treated individually in the VSV processor with 138°C saturated steam for 0.1 s. Initial and intermittent vacuum times were 0.1 s, and the final vacuum time was 0.5 s. Two or three VSV cycles were used on each of the 24 cantaloupes.

Preparation of fresh-cut pieces. All utensils and equipment used for preparing fresh-cut pieces were sanitized with 200 ppm chlorinated water (prepared from sodium hypochlorite after pH adjustment to 6.4 with citric acid). Treated and untreated whole melons were cut into four sections with a sterile knife (sanitized between each melon), and the rinds were carefully removed. Fresh-cut pieces (~3-cm cubes, ~500 g) from multiple treated melons were pooled, placed inside a 9.75-in. (24.75-cm) three-pocket tub tall plastic bowl (Mach 2, Rock-Tenn Company, Franklin Park, Ill.), stored at 5, 10, or 22°C, and evaluated by microbiological tests and physical observation for the presence of mold. Instrumental sensorial quality determinations were made during storage at 5 or 10°C for up to 9 days.

Microbiological analysis of melon surfaces. Rind plugs removed from 24 whole melons were used for microbiological analysis. A sanitized stainless steel cork-borer was used to cut through the cantaloupe rind surface at random locations to produce rind plugs 22 mm in diameter with a rind surface area of 3.80 cm^2. Flesh adhering to the rind plugs was trimmed off with a sterile stainless steel knife. Rind plugs (60 per cantaloupe) weighing approximately 20 g were blended (speed level 5; Waring commercial blender, Dynamic Corp., New Hartford, Conn.) for 1 min with 80 ml of sterile 0.1% peptone water (BBL-Difco, Becton Dickinson, Sparks, Md.). Decimal dilutions of the sample were made with 0.1% peptone water, and aliquots (0.1 ml) were plated in duplicate on a range of media. Plate count agar plates (BBL-Difco, Becton Dickinson) incubated at 30°C for 3 days were used for enumeration of mesophilic aerobes. *Pseudomonas* spp. were enumerated by plating 0.1 ml on *Pseudomonas* isolation agar (BBL-Difco, Becton Dickinson) and incubating at 27°C for 3 days. Yeasts and molds were enumerated on Czapek malt agar (Sigma, St. Louis, Mo.) incubated at 25°C for 5 days. Biochemical tests (API 20E, bioMérieux Vitek, Marcy l'Etoile, France) including the oxidase test, Hugh Leifson, H_2S, urea agar, catalase, and Voges-Proskauer procedures were performed to identify the surviving organisms.

Microbiological analysis of fresh-cut pieces. Fresh-cut pieces stored at 5 and 10°C were monitored for the presence and growth of mesophilic bacteria, yeasts and molds, and *Pseudomonas* spp. every 3 days for up to 9 days. Fresh-cut pieces (100 g) and 200 ml of 0.1% peptone water were added to a stomacher bag (Fisher Scientific, Pittsburgh, Pa.) and pummeled for 30 s in a stomacher (model 400, Dynatech Laboratories, Alexandria, Va.) at medium speed. Undiluted samples or samples from decimal serial dilutions prepared in 0.1% peptone water were surface plated in duplicate onto the media listed above.

To determine the acceptability of the fresh-cut pieces based on physical observation, fresh-cut pieces prepared from treated and untreated whole cantaloupes were monitored for the presence of viable yeasts and molds during storage at 5, 10, and 22°C every 2 days for up to 14 days.

Quality evaluation: texture measurement and color analysis. Texture of fresh-cut pieces was evaluated every 3 days during storage with a TA-XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale, N.Y.) as described previously. A 6-mm-diameter probe was used to penetrate the middle points between the original rind side and the original cavity side of samples to a depth of 10 mm at 10 mm/s. Five pieces were collected for firmness measurements, and the maximum force and area under the curve were recorded using Texture Expert software (version 1.22, Texture Technologies).

Color (CIE L*, a*, and b*) was measured every 3 days during storage with a ColorQuest XE colorimetric spectrophotometer (Hunter Associates Lab, Reston, Va.) with a 1-cm measuring aperture. The spectrophotometer was calibrated using the standard light trap and a white tile (L* 93.50, a* −0.89, and b* 1.01). The illuminant was D65, and the viewing field was 10°. Two readings were taken on randomly selected opposite cut surfaces of each piece. Five of eight pieces per plate were measured for each experiment. Hue and chroma values were calculated from the following equations: hue = $\tan^{-1}(b^*/a^*)$ and chroma = $(a^{*2} + b^{*2})^{1/2}$.

Data analysis. All experiments were performed in triplicate with duplicate samples analyzed at each sampling time. Data were subjected to an analysis of variance with the Statistical Analysis System (SAS Institute, Cary, N.C.). of differences in mean values of bacterial cell counts on treated and untreated cantaloupe were considered significant at $P < 0.05$ using the Bonferroni least significant difference method *(18)*.

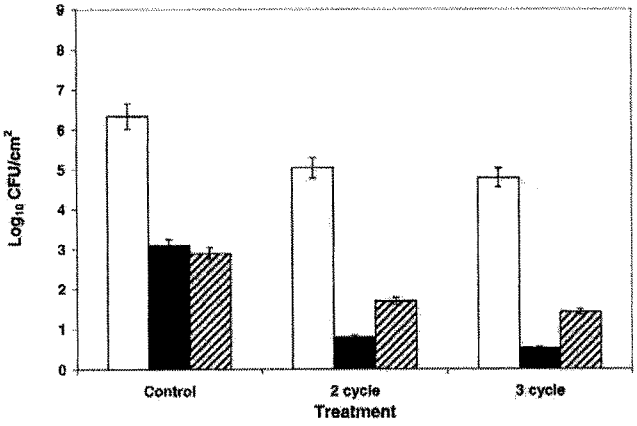

FIGURE 1. *Effect of VSV treatment on populations of aerobic mesophilic bacteria, yeasts and molds, and* Pseudomonas *spp. on cantaloupe surfaces. Values are mean ± standard error (SE) from three separate experiments.* □, *Aerobic mesophilic bacteria;* ■, *yeasts and molds;* ▨, Pseudomonas *spp.*

RESULTS AND DISCUSSION

Effects of VSV treatment on native microflora of whole cantaloupe. Mean microbial populations on the control cantaloupe surfaces were 6.39 log CFU/cm^2 for total mesophilic aerobes, 3.09 log CFU/cm^2 for yeasts and molds, and 2.89 log CFU/cm^2 for *Pseudomonas* spp. (Fig. 1). VSV treatments of two or three cycles resulted in a significant reduction of aerobic mesophilic bacteria (~1 log CFU/cm^2), yeasts and molds (~2 log CFU/cm^2), and *Pseudomonas* spp. (~1 log CFU/cm^2) on cantaloupe surfaces as compared with controls. Population reductions for yeasts and molds and *Pseudomonas* spp. were not significantly different between cantaloupes treated with two and those treated with three cycles (Fig. 1). In a preliminary VSV study, treated cantaloupes showed no evidence of visual damage, decay, or weight loss during storage at 5°C for 9 days. In our previous study in which hot water treatment was used to decontaminate whole melon surfaces, we reported no visual damage or decay but noticed a minimal weight loss during storage at 4°C *(31)*. In contrast to the treated cantaloupe, untreated controls had mold growth in the stem scar area as early as 6 days of storage at 5°C.

Effect of VSV treatment on transfer of surface microflora. Figure 2 shows the efficacy of the VSV treatments in reducing transfer of spoilage microflora from the surfaces of whole cantaloupes to fresh-cut pieces during preparation. The treatments at two or three cycles significantly reduced yeasts and molds (which cause decay of whole melon and fresh-cut pieces during storage) to below the level of detection (<1 CFU/g) but did not achieve significant reductions in the populations of mesophilic aerobes and *Pseudomonas* spp. transferred to fresh-cut pieces. Mesophilic aerobes, yeasts and molds, and *Pseudomonas* spp. transferred to fresh-cut pieces survived and grew during storage at 5 and 10°C (Figs. 3 and 4). Each of these populations was higher in fresh-cut pieces from untreated cantaloupes than in pieces from VSV-treated cantaloupes at both storage temperatures. Yeasts and molds were not recovered for up to 3 days of storage at 5°C from fresh-cut pieces of cantaloupe processed for two and three VSV cycles (Fig. 3). At day 6 and 9, yeast and mold populations were recovered, and the populations at day 9 were slightly higher than those on day 6. Similar but higher populations of yeasts and molds were found in fresh-cut pieces during storage at 10°C for 9 days (Fig. 4). The relatively slow growth of yeasts and molds and *Pseudomonas* spp. on fresh-cut pieces from treated cantaloupes compared with growth on pieces from untreated cantaloupes may have been due to gradual recovery of injured cells during storage.

Effect of VSV treatment on results of physical observation for presence of yeasts and molds on fresh-cut cantaloupe pieces. The results of a study designed to monitor physical appearance and growth of yeasts and molds in fresh-cut cantaloupe pieces during subsequent storage at 5, 10, or 22°C for up to 14 days are shown in Tables 1 and 2. Visual inspection revealed a slimy appearance on some of the samples during storage, particularly on samples

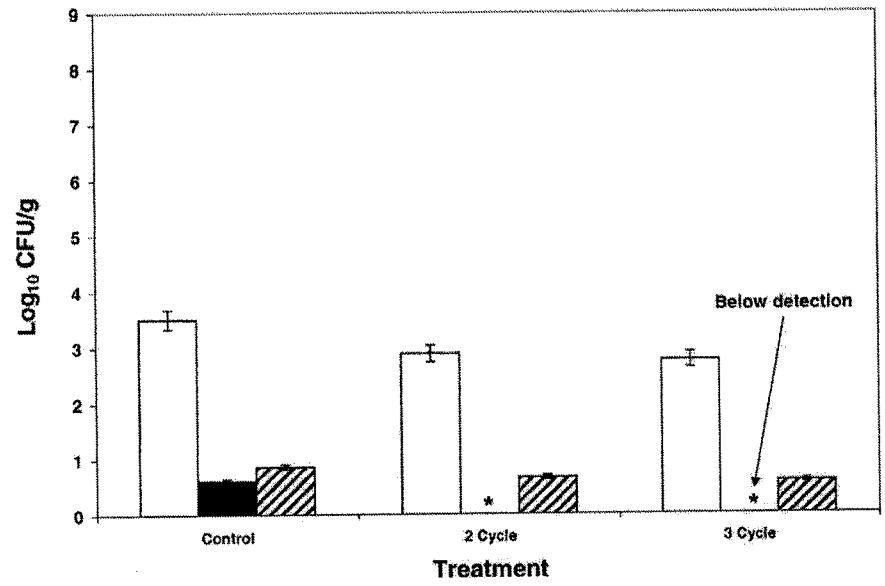

FIGURE 2. *Effect of VSV treatment on transfer of aerobic mesophilic bacteria, yeasts and molds, and* Pseudomonas *spp. on cantaloupe surfaces to fresh-cut pieces during cutting. *, below detection of <1 CFU. Values are mean ± SE from three separate experiments.* □, *Aerobic mesophilic bacteria;* ■, *yeasts and molds;* ▨, Pseudomonas *spp.*

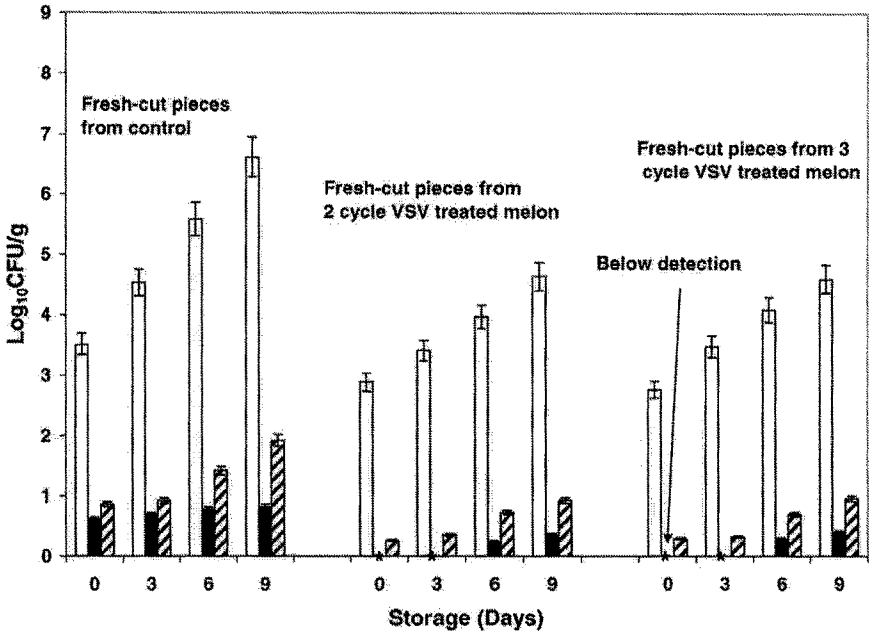

FIGURE 3. *Survival and growth of aerobic mesophilic bacteria, yeasts and molds, and* Pseudomonas *spp. on fresh-cut pieces prepared from whole cantaloupes treated with VSV during storage at 5°C for 9 days. *, below detection of <1 CFU/g. Values are mean ± SE from three separate experiments.* □, *Aerobic mesophilic bacteria;* ■, *yeasts and molds;* ▨, Pseudomonas *spp.*

stored at 10 or 22°C. Sliminess was observed by day 6 of storage at 10°C and by day 9 at 5°C. At 22°C, yeast and mold spots were observed on fresh-cut pieces by day 2 (Table 1). The study was terminated at day 4 because of the presence of slime, odor, and mold. Although, yeasts and molds were detected at day 3 in fresh-cut pieces stored at 5°C, physical yeast and mold spots appeared on the fresh-cut pieces from untreated cantaloupes at days 8, 6, and 2 of storage at 5, 10, and 22°C, respectively (Table 1). At 10°C, the maximum storage time for cut cantaloupe was less than 6 days, whereas at 5°C, shelf life was extended just past 6 days. The 6-day samples stored at 10°C were slimy and translucent, with no commercial value. In fresh-cut pieces prepared from VSV-treated cantaloupes, yeast and mold spots were not observed during storage at 5°C for up to 14 days but were seen in samples stored at 10°C at 10 days. When the fresh-cut pieces were stored at 22°C, yeast and mold spots appeared by day 4 (Table 2). There was no consistent difference in appearance between samples treated for two or three VSV cycles; however, samples from both VSV treatments had no yeast or mold spots or had fewer spots than did control samples.

Effect of VSV on quality changes. The L* values of the cantaloupe pieces prepared from fruits that were treated with VSV (either two cycles or three cycles) were higher (but not always significantly higher) than those of the controls by day 9 of storage at either 5 or 10°C (Table 3). The higher *L values indicate that VSV treatments preserved the lightness of the cantaloupe samples during posttreatment storage. The a* values of the controls and of samples treated with VSV were unchanged during storage at 5°C.

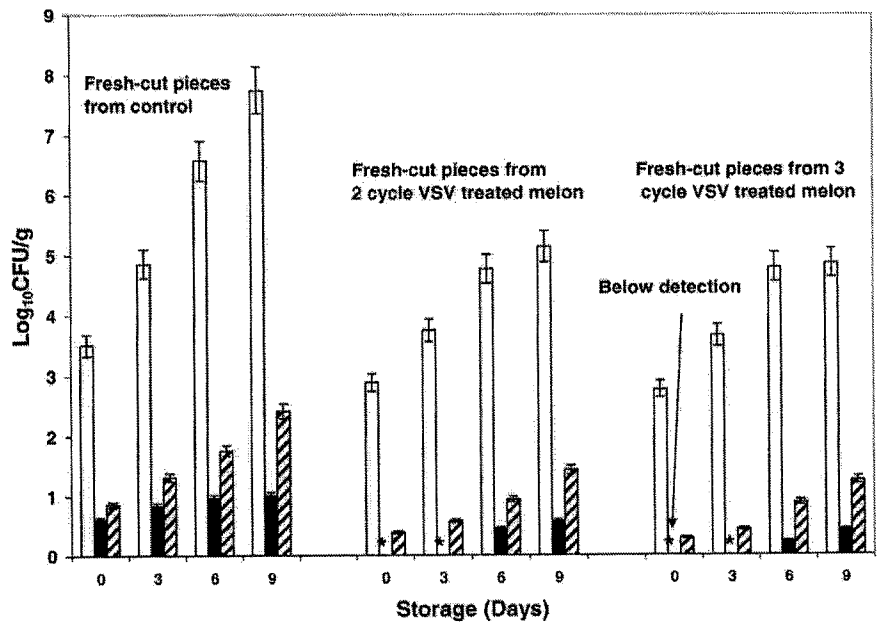

FIGURE 4. *Survival and growth of aerobic mesophilic bacteria, yeasts and molds, and* Pseudomonas *spp. on fresh-cut pieces prepared from whole cantaloupes treated with VSV during storage at 10°C for 9 days. *, below detection of <1 CFU/g. Values are mean ± SE from three separate experiments.* □, *Aerobic mesophilic bacteria;* ■, *yeasts and molds;* ▨, Pseudomonas *spp.*

TABLE 1. *Physical observation of fresh-cut cantaloupe pieces for the presence of yeast and mold spots during storage at different temperatures for 14 days*[a]

Temp (°C)	Storage day: 0	2	4	6	8	10	12	14
5	–	–	–	–	+	+	+	+
10	–	–	–	+	+	+	+	+
22	–	+	NA[b]					

[a] Fresh-cut pieces were prepared from untreated whole cantaloupes. Results are based on three trials and duplicate physical observations of fresh-cut pieces.

[b] NA, not applicable. Experiment was stopped because of extensive spoilage.

TABLE 2. *Physical observation of fresh-cut pieces prepared from VSV-treated whole cantaloupes for the presence of yeast and old spots during storage at different temperatures for 14 days*[a]

Temp (°C)	Storage day: 0	2	4	6	8	10	12	14
5	–	–	–	–	–	–	–	–
10	–	–	–	–	–	+	+	+
22	–	–	+	+	NA[b]			

[a] Fresh-cut pieces were prepared immediately after VSV treatment. Results are based on three trials and duplicate physical observations of fresh-cut pieces.

[b] NA, not applicable. Experiment was stopped because of extensive spoilage.

However, during storage at 10°C, the a* values of all samples decreased by day 6, indicating that these samples had a shorter shelf life than those stored at 5°C. There was no consistent effect of VSV on b* values of samples stored either at 5 or at 10°C except that the b* values of samples treated with VSV were significantly higher than those of the controls on day 9 at 10°C. The reason for the higher b* values in VSV-treated samples probably is the absence of yeast and mold spots (Table 2). Hue angles of samples treated with VSV were generally similar to those of the controls during the entire storage period at both temperatures. Similarly, there was no consistent difference in chroma values between VSV-treated samples and the controls, except that on day 9 at 10°C control samples had significantly lower chroma values than did treated samples, indicating that VSV treatment preserved the saturation of cantaloupe color. There was no consistent difference in any of the color parameters for samples from the two VSV treatments. It is unlikely that consumers could distinguish the color differ-

TABLE 3. *Changes in color and texture during storage at 5 and 10°C of fresh-cut cantaloupe pieces prepared from fruit treated by VSV*[a]

Temp (°C)	Storage day	Treatment	Color L*	Color a*	Color b*	Color Hue	Color Chroma	Texture Maximum force (g)	Texture Area under the curve
5	0	Control	64.6 B	13.1 A	25.0 A	62.3 B	28.2 A	1,551 A	5,877 A
		2VSV	65.9 AB	12.0 A	24.1 A	63.4 AB	27.0 AB	1,688 A	6,189 A
		3VSV	67.7 A	11.1 B	22.9 A	64.0 A	25.5 B	1,811 A	6,770 A
	3	Control	63.3 B	11.7 A	23.1 A	63.2 A	25.9 A	1,264 B	4,728 A
		2VSV	65.7 A	11.2 AB	23.4 A	64.3 A	26.0 A	1,401 AB	5,322 A
		3VSV	65.3 AB	10.9 B	22.7 A	64.3 A	25.2 A	1,745 A	6,502 A
	6	Control	63.2 A	12.3 A	24.1 A	63.1 A	27.1 A	1,200 A	4,246 A
		2VSV	67.1 A	11.6 B	23.3 AB	64.4 A	25.8 AB	1,182 A	4,563 A
		3VSV	66.5 A	11.1 AB	22.1 B	64.2 A	24.5 B	1,609 A	6,057 A
	9	Control	61.5 B	12.0 A	23.5 A	62.8 B	26.5 A	2,303 A	8,839 A
		2VSV	66.4 A	12.5 A	25.5 A	63.9 A	28.4 A	1,690 A	6,421 A
		3VSV	66.3 A	11.6 A	24.5 A	64.6 A	27.1 A	2,673 A	9,633 A
10	0	Control	65.7 A	13.0 A	24.9 AB	62.4 B	28.1 A	1,428 A	5,648 A
		2VSV	67.5 A	10.9 B	23.8 B	65.3 A	26.2 B	1,223 A	4,746 A
		3VSV	66.8 A	12.6 A	25.7 A	63.7 B	28.6 A	1,691 A	6,084 A
	3	Control	59.4 B	10.4 A	20.2 B	62.5 B	22.7 B	1,347 A	5,016 A
		2VSV	66.8 A	10.6 A	23.6 A	65.5 A	25.9 A	1,080 A	4,285 A
		3VSV	61.3 B	11.4 A	22.0 AB	62.8 B	24.8 AB	1,287 A	4,802 A
	6	Control	59.2A	9.1 A	19.4 A	64.9 A	21.4 A	1,109 A	3,822 A
		2VSV	61.8 A	9.0 A	19.5 A	64.6 A	21.5 A	1,088 A	4,283 A
		3VSV	63.5 A	10.4 A	21.6 A	64.0 A	24.0 A	1,475 A	5,579 A
	9	Control	52.8 C	7.3 B	15.8 B	65.2 A	17.4 C	1,210 B	4,232 B
		2VSV	64.6 A	9.9 A	23.9 A	67.6 A	25.9 A	1,330 B	5,116 B
		3VSV	58.3 B	9.4 A	19.0 B	63.7 B	21.2 B	2,444 A	9,335 A

[a] Fruit were treated with two cycles (2VSV) and three cycles (3VSV) of a vacuum-steam-vacuum process. Values are means from three separate experiments with duplicate determinations. Within the same storage day and among treatments, means with different letters are significantly different ($P < 0.05$, least significant difference test).

ence among samples from the three experimental groups except for samples stored for 9 days at 10°C.

VSV treatment had no consistent effect on texture of cut cantaloupe in terms of either maximum force or area (Table 3). Day-to-day variability in textural parameters could have been due to variation in ripeness among melons.

The results of a previous study designed to evaluate the shelf life of minimally processed honeydew and cantaloupe melons, kiwifruit, papaya, and pineapple stored at 4°C indicated that both the shelf life and type of spoilage were related to the type of fruit *(25)*. The authors suggested that the microflora of fruit pieces should be identified so that appropriate criteria for quality assessment can be determined. The predominant organisms on cantaloupe and honeydew melon were aerobic mesophilic bacteria followed by lactic acid bacteria, gram-negative bacteria, yeasts and molds, and *Pseudomonas* spp. *(28)*. In unwrapped and wrapped sliced watermelon, *Pseudomonas* spp., *Escherichia coli, Enterobacter* spp., and micrococci were predominant *(1)*. Fresh-cut vegetables initially harbor lower numbers of microorganisms than do unwashed whole vegetables because whole vegetables to be cut are washed in chlorinated water before cutting *(14)*. In this study, the VSV treatment reduced the populations of native microflora of cantaloupe surfaces and significantly reduced ($P < 0.05$) transfer to fresh-cut pieces. Reductions in the populations of mesophilic aerobes on cantaloupe surfaces resulting from VSV treatment were substantially less than those obtained by immersion of melon in hot water *(31)*. In the hot-water study, the native microflora on whole cantaloupes was reduced by approximately 4.5 log units. Similarly, Annous et al. *(2)* found that hot water surface pasteurization of cantaloupes with pilot-scale equipment enhanced microbiological safety and extended shelf life. The VSV treatments did not result in significant log reductions of surface microflora of cantaloupe as was observed with the hot water treatment, possibly because exposure time (1 to 2 min) to the hot water was longer than the 1.25 s of steam exposure with the VSV process. The efficacy of VSV treatment for inactivating human pathogens on cantaloupes and other heat-tolerant fruits and vegetables should be investigated.

In our previous study, we found increases in populations of all groups of microorganisms, including *Pseudomonas* spp., in all fresh-cut cantaloupes as storage time increased, regardless of the treatment. Boyette et al. *(5)* reported that the microbial decay of minimally processed lettuce is largely due to the growth of microorganisms originating from preharvest environments. Gram-negative bacteria and smaller numbers of yeasts make up the bulk of the initial microbial flora of vegetables *(8, 9, 11, 15, 16)*. In stored shredded lettuce, mesophilic aerobic bacteria and psychrotrophic microorganisms tend to predominate, while molds and lactic acid bacteria generally remain at low concentrations *(3, 9, 17)*. In this study, yeasts, molds, and *Pseudomonas* spp. on fresh-cut cantaloupe pieces were below the limit of detection; however, as days of refrigerated storage increased, aerobic mesophilic microbes, *Pseudomonas* spp., and yeasts and molds were detected in all samples from untreated whole cantaloupe. The same categories of microorganisms were detected on whole melon surfaces and on fresh-cut pieces during storage, which indicates that the microbes were transferred from the rind to the flesh during preparation of fresh-cut pieces. A similar finding has been reported for transfer of *Salmonella* Stanley from cantaloupe surfaces to fresh-cut pieces *(30)*. VSV decontamination of whole cantaloupes designated for fresh-cut processing led to a significant reduction of *Pseudomonas* spp., yeasts, and molds on melon surfaces, thus reducing the probability of transfer from the rind to the interior tissue during cutting. The reduced populations of such yeasts, molds, and *Pseudomonas* spp. in fresh-cut cantaloupe would improve the microbial quality of the product. Cantaloupe rind acts as an effective insulator, and if steam exposure is minimal, the internal flesh used for fresh-cut preparation will be little affected, as indicated by the sensory data. The visual signs of deterioration of fresh-cut produce are flaccidity due to loss of water, changes in color due to oxidative browning at the cut surfaces, and microbial contamination *(7, 10, 27, 32–34)*. In our study, visual inspection of fresh-cut cantaloupe after two and three cycles VSV treatments did not reveal any of these spoilage signs for up to 10 days of storage at 5°C. VSV treatment of whole cantaloupe probably inactivated or injured some of these microbes, thus inhibiting microbial growth and extending the refrigerated shelf life.

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REFERENCES

1. Abbey, S. D., E. K. Heaton, D. A. Golden, and L. R. Beuchat. 1988. Microbiological and sensory quality changes in unwrapped and wrapped sliced watermelon. *J. Food Prot.* 51:531–533.
2. Annous, B. A., B. Angela, and J. E. Sites. 2004. Surface pasteurization of whole fresh cantaloupes inoculated with *Salmonella* Poona or *Escherichia coli*. *J. Food Prot.* 67:1876–1885.
3. Barriga, M. I., G. Trachy, C. Willenot, and R. E. Simard. 1991. Microbial changes in shredded iceberg lettuce stored under controlled atmosphere. *J. Food Sci.* 56:1586–1599.
4. Beuchat, L. R. 1995. Pathogenic microorganisms associated with fresh produce. *J. Food Prot.* 59:204–216.
5. Boyette, M. D., D. F. Ritchie, S. J. Carballo, S. M. Blankenship, and D. C. Sanders. 1993. Chlorination and postharvest disease control. *Hort. Technol.* 3:395–400.
6. Brackett, R. E. 1992. Shelf stability and safety of fresh produce as influenced by sanitation and disinfection. *J. Food Prot.* 55:808–814.
7. Brecht, J. K. 1995. Physiology of lightly processed fruits and vegetables. *HortScience* 30:18–22.
8. Carlin, F., C. Nguyen-The, and A. A. D. Silva. 1995. Factors affecting the growth of *Listeria monocytogenes* on minimally processed fresh endive. *J. Appl. Bacteriol.* 78:636–646.
9. Garg, N., J. J. Churey, and D. F. Splittstoesser. 1990. Effect of processing conditions on the microflora of fresh-cut vegetables. *J. Food Prot.* 53:701–703.
10. King, A. D., Jr., and H. R. Bolin. 1989. Physiology and microbiological storage stability of minimally processed fruits and vegetables. *Food Technol.* 2:132–135.
11. King, A. D., Jr., J. A. Magnusson, T. Torok, and N. Goodman. 1991. Microbial studies on shelf life of cabbage and coleslaw. *Appl. Environ. Microbiol.* 31:404–407.

12. Kozempel, M., N. Goldberg, and J. C. Craig, Jr. 2003. Development of a new process to reduce bacteria on solid foods without thermal damage—the VSV (vacuum/steam/vacuum) process. *Food Technol.* 57(12):30–33.
13. Kozempel, M., N. Goldberg, E. R. Radewonuk, and O. J. Scullen. 2000. Commercial testing and optimization studies of the surface pasteurization process of chicken. *J. Food Proc. Eng.* 23:387–402.
14. Li, Y., R. E. Brackett, R. L. Shewfelt, and L. R. Beuchat. 2001. Changes in appearance and natural microflora on iceberg lettuce treated in warm, chlorinated water and then stored at refrigeration temperature. *Food Microbiol.* 18:299–308.
15. Magnuson, J. A., A. D. King, Jr., and T. Torok. 1990. Microflora of partially processed lettuce. *Appl. Environ. Microbiol.* 56:3851–3855.
16. Manvell, P. M., and M. R. Ackland. 1986. Rapid detection of microbial growth in vegetable salads at chill and abuse temperatures. *Food Microbiol.* 3:59–65.
17. Marchetti, R., M. A. Casadei, and M. E. Guerzoni. 1992. Microbial population dynamics in ready-to-use vegetable salads. *Ital. J. Food Sci.* 2:97–108.
18. Miller, R. G., Jr. 1981. Simultaneous statistical inference, 2nd ed., p. 67–70. Springer-Verlag, New York.
19. Morgan, A. I. 25 January 1994. Method and apparatus for treating and packaging raw meat. U.S. patent 5,281,428.
20. Morgan, A. I., and R. A. Carlson. 1960. Steam injection heating. *Ind. Eng. Chem.* 52:219–220.
21. Morgan, A. I., N. Goldberg, E. R. Radewonuk, and O. J. Scullen. 1996. Surface intervention of raw poultry meat by steam. *Lebensm. Wiss. Technol.* 29:447–451.
22. Morgan, A. I., E. R. Radewonuk, and O. J. Scullen. 1996. Ultra high temperature, ultra short time surface intervention of meat. *J. Food Sci.* 61:1216–1218.
23. National Advisory Committee on Microbiological Criteria for Foods. 1999. Microbiological safety evaluations and recommendations on fresh produce. *Food Control* 10:117–143.
24. Nguyen-The, C., and F. Carlin. 1994. The microbiology of minimally processed fresh fruits and vegetables. *Crit. Rev. Food Sci. Nutr.* 34: 371–401.
25. O'Connor-Shaw, R. E., R. Roberts, A. L. Ford, and S. M. Nothingham. 1994. Shelf life of minimally processed honeydew, kiwifruit, papaya, pineapple and cantaloupe. *J. Food Sci.* 59:1202–1206.
26. Richardson, S. D., A. D. Thurston, Jr., T. V. Caughran, T. W. Collette, K. S. Patterson, and B. W. Lykins, Jr. 1998. Chemical by-products of chlorine and alternative disinfectants. *Food Technol.* 52:58–61.
27. Shewfelt, R. L. 1987. Quality of minimally processed fruits and vegetables. *J. Food Qual.* 10:143–156.
28. Ukuku, D. O., and W. F. Fett. 2002. Effectiveness of chlorine and nisin-EDTA treatments of whole melons and fresh-cut pieces for reducing native microflora and extending shelf life. *J. Food Saf.* 22: 231–253.
29. Ukuku, D. O., A. V. Pilizota, and G. M. Sapers. 2001. Influence of washing treatment on native microflora and *Escherichia coli* population of inoculated cantaloupes. *J. Food Saf.* 21:31–47.
30. Ukuku, D. O., and G. M. Sapers. 2001. Effect of sanitizer treatment on *Salmonella* Stanley attached to the surface of cantaloupe and cell transfer to fresh-cut tissues during cutting practices. *J. Food Prot.* 64:1286–1291.
31. Ukuku, D. O., P. Vlasta, and G. M. Sapers. 2004. Effect of hot water and hydrogen peroxide treatment on survival of *Salmonella* and microbial quality of whole cantaloupe and fresh-cut cantaloupe. *J. Food Prot.* 67:432–437.
32. Varoquaux, P., and R. C. Wiley. 1994. Biological and biochemical changes in minimally processed refrigerated fruits and vegetables, p. 226–268. *In* R. C. Wiley (ed.), Minimally processed refrigerated fruits and vegetables. Chapman and Hall, New York.
33. Watada, A. E., K. Abe, and N. Yamuchi. 1990. Physiological activities of partially processed fruits and vegetables. *Food Technol.* 44: 116–122.
34. Wei, C.-I., D. L. Cook, and J. R. Kirk. 1985. Use of chlorine compounds in the food industry. *Food Technol.* 1:107–115.